XII International Workshop
on Deep Inelastic Scattering

The "Underlying Event" at CDF

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Štrbské Pleso, Slovakia

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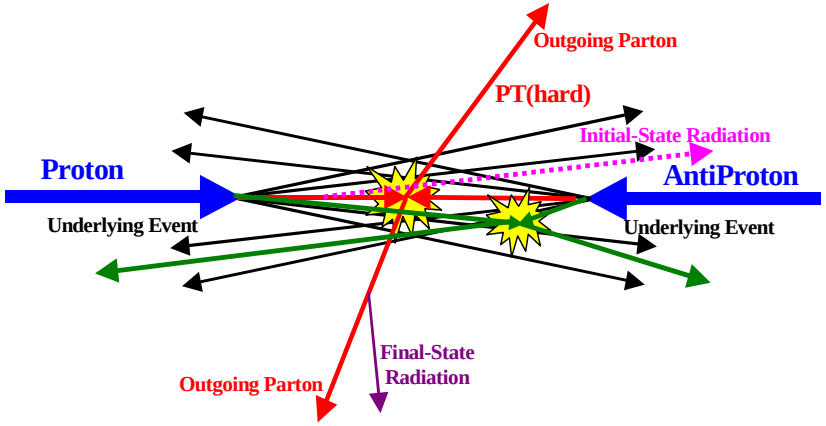
Outline

Motivations:
"underlying event"
is ***not*** a
well understood
object



Phenomenologically:
may be made of
everything
except
hard scattered jets

1. Topology of "minimum-bias" and "hard" collisions:
   - study transverse regions sensitive to the underlying event.
   - look to "beam-beam remnant" and multiple parton interaction component of underlying event in back-to-back jet collisions.
2. Jet structure in the underlying event:
   - $\Delta\phi$ correlations in the particle density "associated" to the maximum P_T particle in the transverse region.
3. Jet structure in underlying event vs in "minimum bias".

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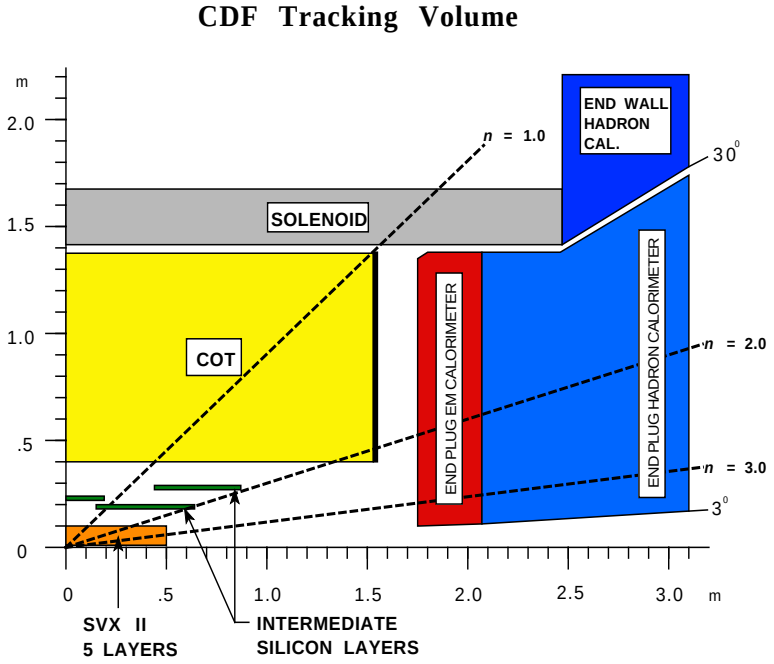
Data selection



Event selection:

1. Zero or one primary vertex
2. $|Z_{vertex}| < 60$ cm
3. $SumE_T < 1.5$ TeV

Track selection:

1. COT measured tracks
2. $|Z\text{-}Z_0| < 2$ cm
3. $|d_0| < 1$ cm
4. $P_T > 0.5$ GeV/c
5. $|\eta| < 1.0$

} $\varepsilon \approx 98\%$ uniform

	Min-Bias	JET20	JET50	JET70	JET100
Total Events	3,716,068	7,388,639	1,844,407	826,597	1,052,530
Selected Events	2,596,553	3,127,001	802,003	352,820	393,118
Sel. Ev. JetClu ($\|\eta$(jet)$\| < 2$, R = 0.7)	587,154	2,473,013	735,893	338,668	389,006

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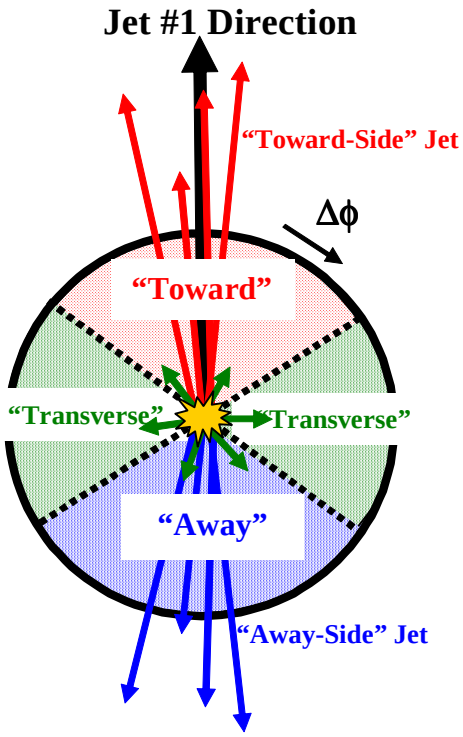
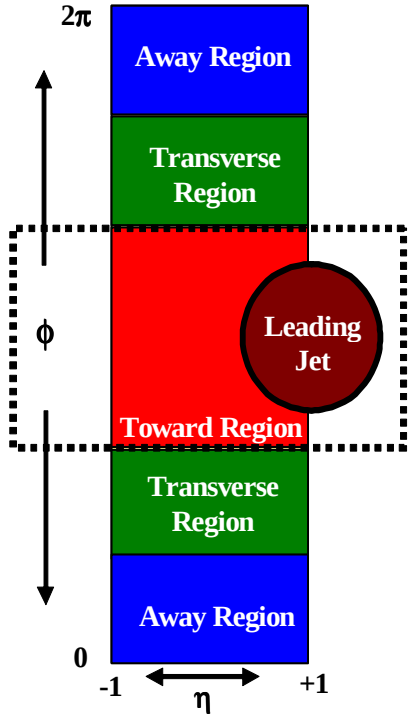
The transverse region



- The direction of the leading calorimeter jet defines three transverse regions in ϕ
- "Toward" = | Δϕ | < 60°
- "Away" = | Δϕ | > 120°
- "Transverse"= 60°<| Δϕ | < 120° (perpendicular to the jet#1 plane)
- Each has same η–ϕ area (ΔηxΔϕ)2/6 = 4π/3
- Jets are defined by JetClu with R=0.7 in |η|<2



"Leading jet" events = E_T(jet#1) > 15 GeV
no restrictions on 2nd highest E_T jet (when present).

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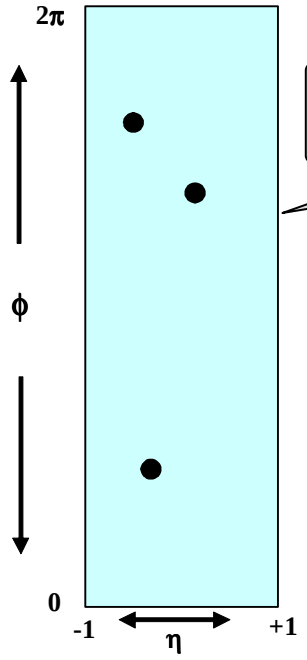
Densities

Study charged particles and form:

1. **particle density $dN_{ch}/d\eta d\phi$**
2. **scalar P_T Sum density: $dSum(P_T)/d\eta d\phi$**

Data uncorrected, but efficiency is high and uniform



Area = $\Delta\eta$ x $\Delta\phi$ = = 2 x 2π = 4π

Es: 3 particles $dN_{ch}/d\eta d\phi$ = = 3/4π = 0.24

Only tracks in: $|\eta|<1.0$ $P_T>0.5$ GeV/c

Systematic due to track selection included in the plots

Divide by 4π

	CDF Run 2 "Min-Bias" Observable	Average	Average Density per unit **η-ϕ**
Nchg	Number of Charged Particles	3.17 +/- 0.31	0.252 +/- 0.025
PTsum (GeV/c)	Scalar p_T sum of Charged Particles	2.97 +/- 0.23	0.236 +/- 0.018

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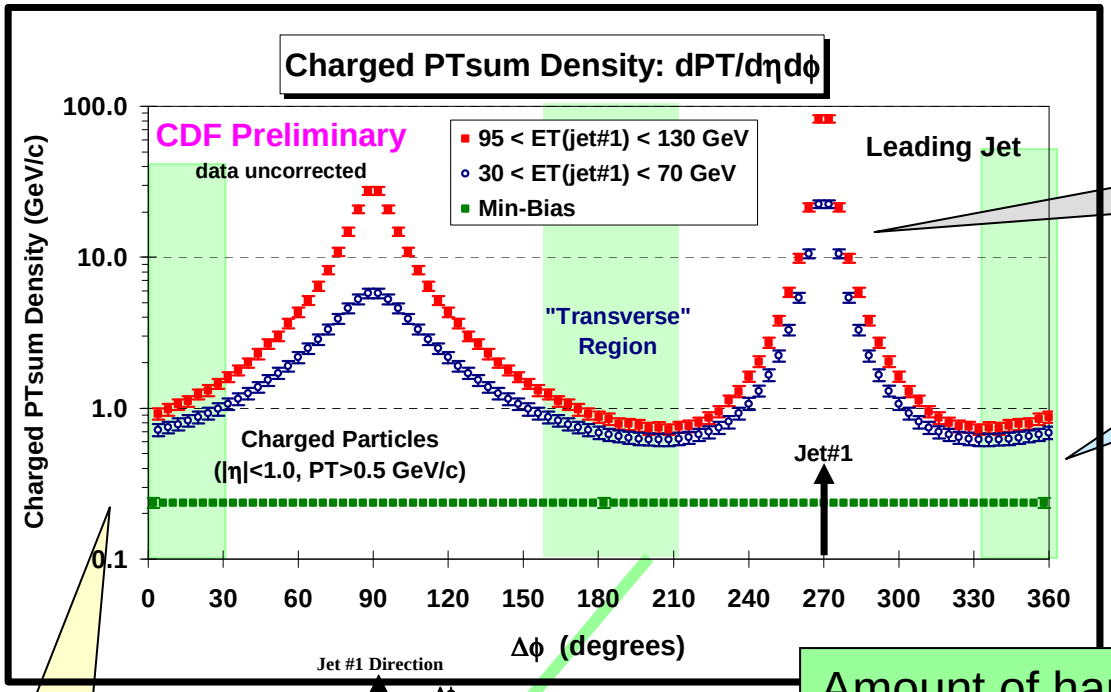
PTsum Density in Transverse region(s)

"Leading jet" events: Δφ dependence of the scalar PTsum density relative to the direction of the leading jet

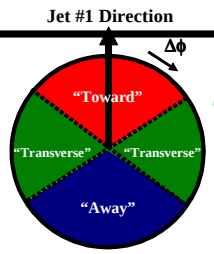


The leading jet is rotated to 270°

Average Min-Bias = 0.24

Same in charged particle density

Notice log scale



transverse regions

Amount of hard initial+final state radiation in transverse region increases with E_T of leading jet…

..see better next slide →

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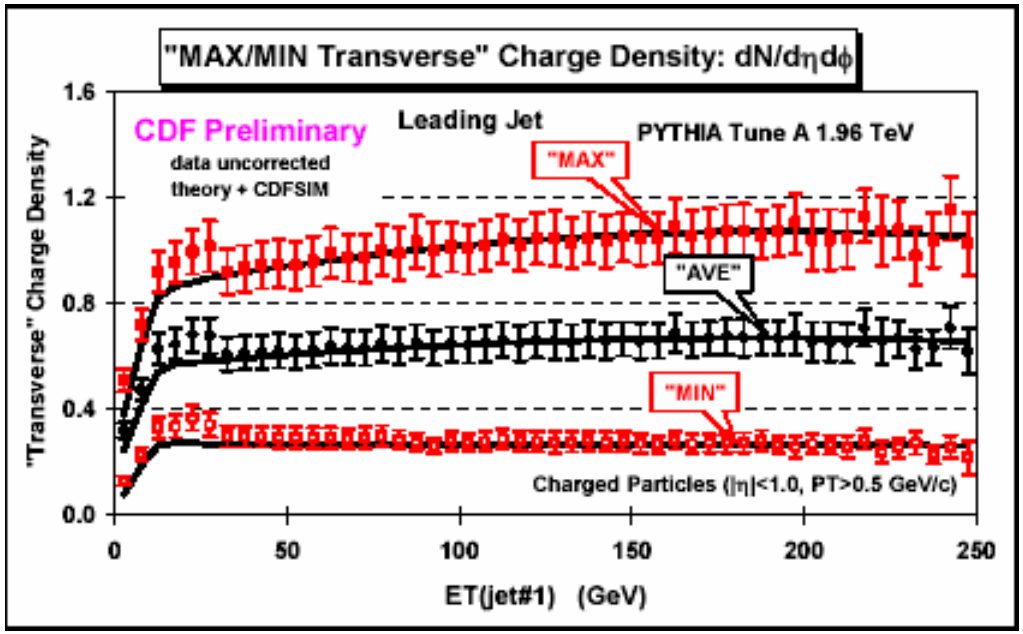
MAX/MIN Transverse Regions

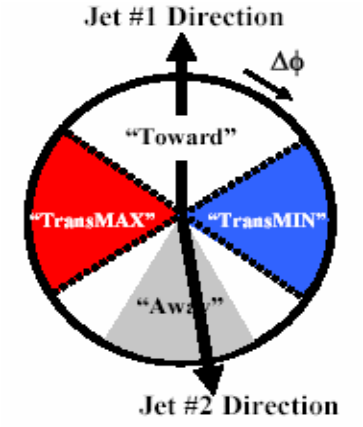
"Leading jet" events: shows the charged particle density as a function of the leading jet E_T

Define "MAX" and "MIN" transverse regions on event-by-event basis :

"MAX" = contains largest number of charged particles

"MIN" = contains smallest number of charged particles





MAX ← gets hardest initial+final state radiation
MIN ← more sensitive to "beam-beam remnant" component of underlying event and to multiple parton interactions

Same in scalar PT sum density

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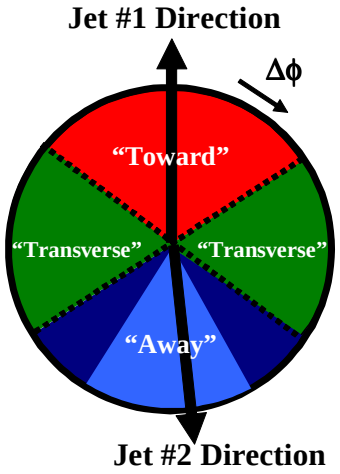
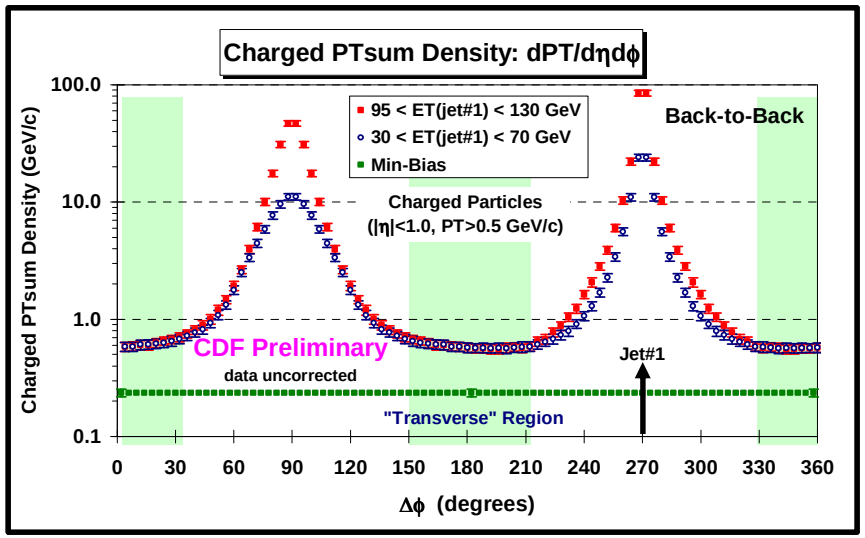
Back-to-back jet events

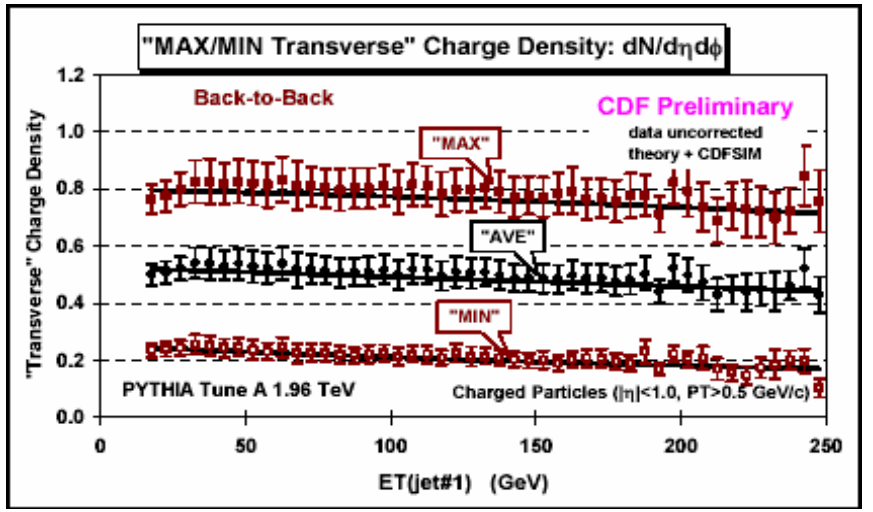
Subset of the "leading jet" events.
Require at least 2 jets with :

1) $\Delta\phi > 150°$
2) $E_T(\text{jet\#2})/E_T(\text{jet\#1})>0.8$
3) no 3rd jet with $E_T>15$ GeV



No increased activity in transverse region





Suppress initial+final state radiation: increase sensitivity of transverse region to beam-beam remnants and multiple parton scattering

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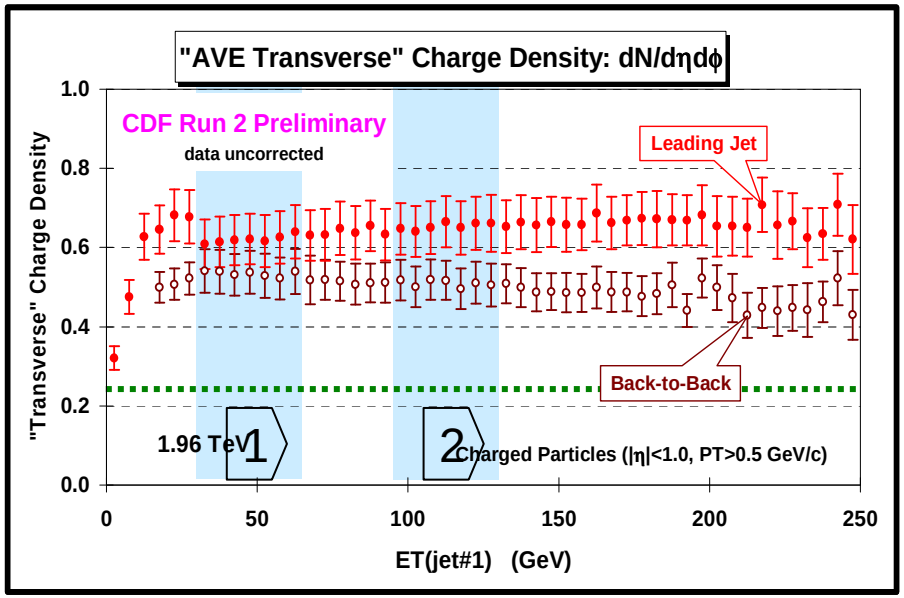
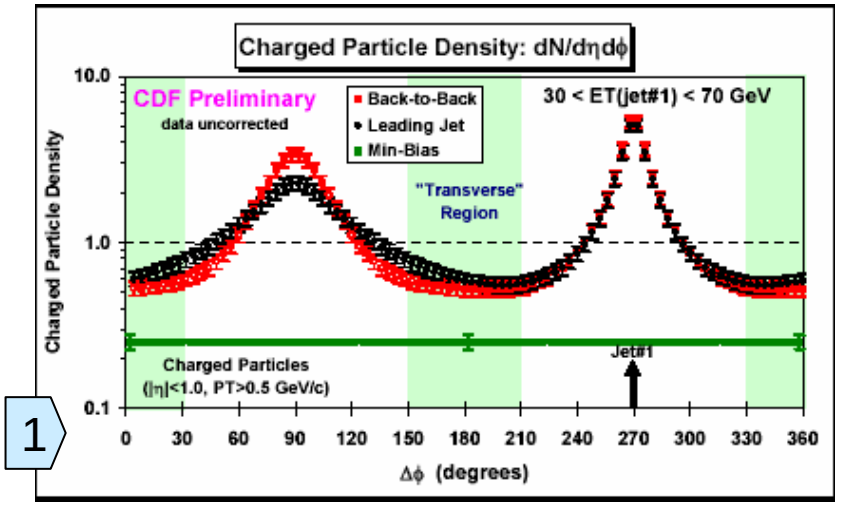
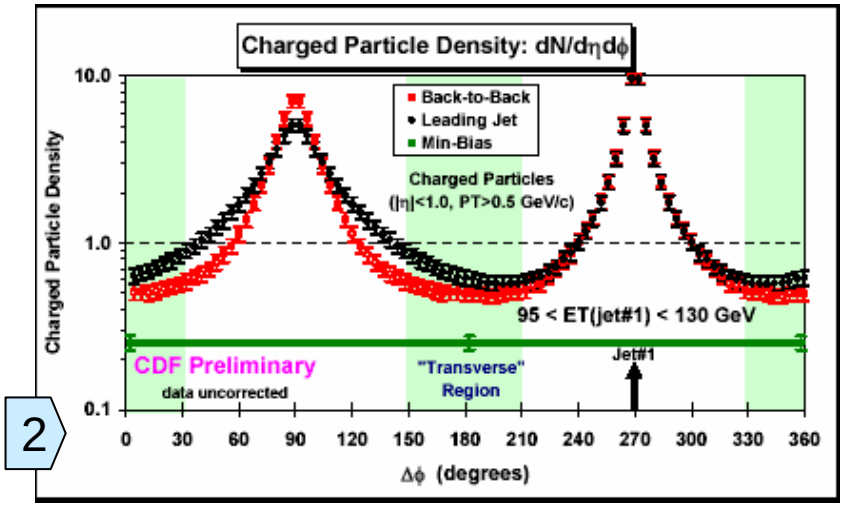
Leading vs b-t-b jets: Ch. Density

Different behavior of "Leading jet" and "Back-to-back jet" events:



With respect to E_T(jet#1), "AVE" densities rise in leading jet and fall in back-to-back events (where initial+final state radiation is suppressed)





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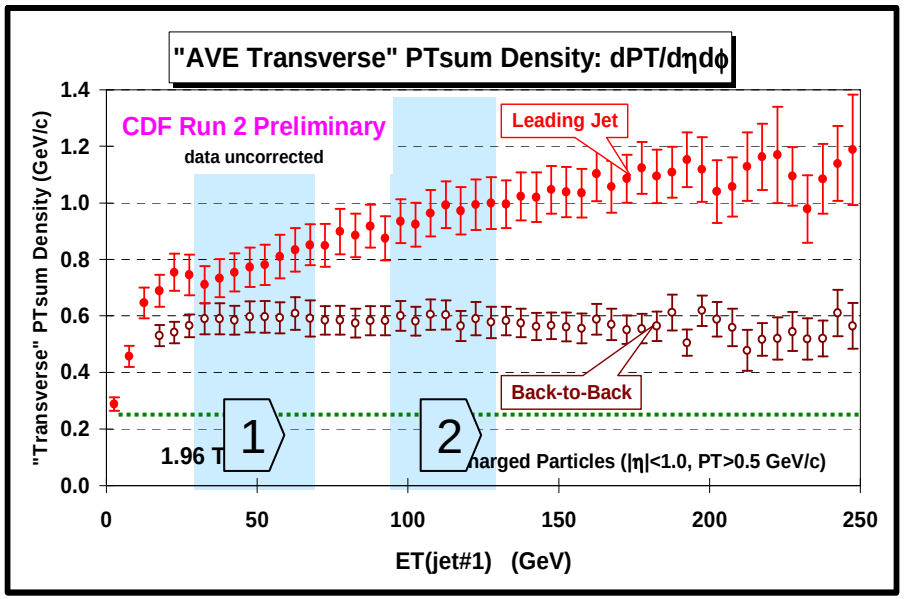
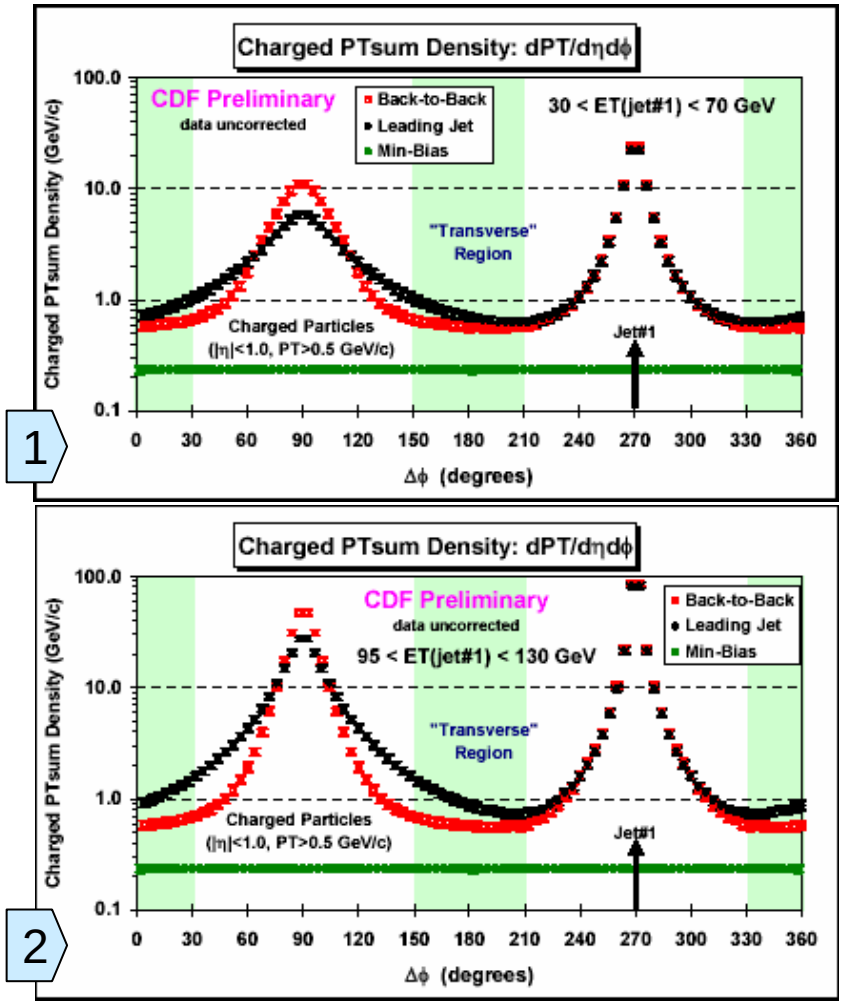
Leading vs b-t-b jets: PTsum Density

Different behavior of "Leading jet" and "Back-to-back jet" events.



Same as previous: shown here the PTsum density



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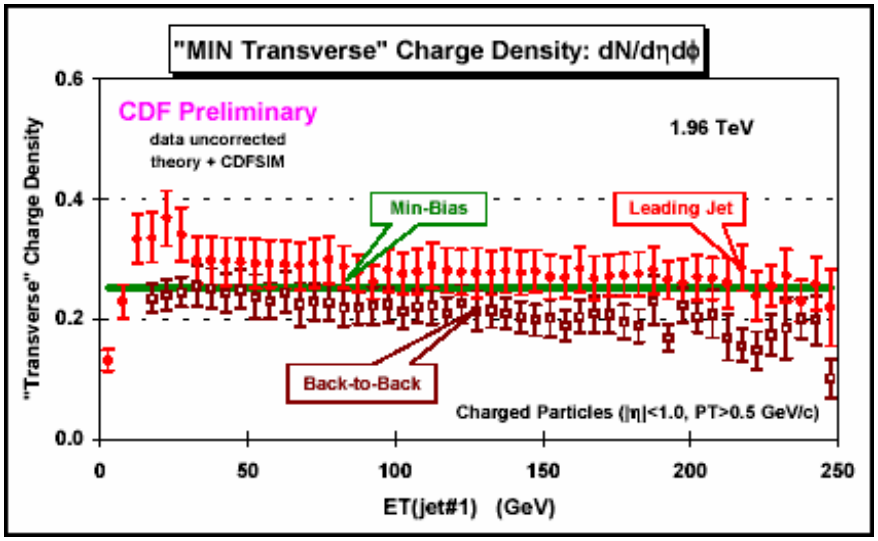
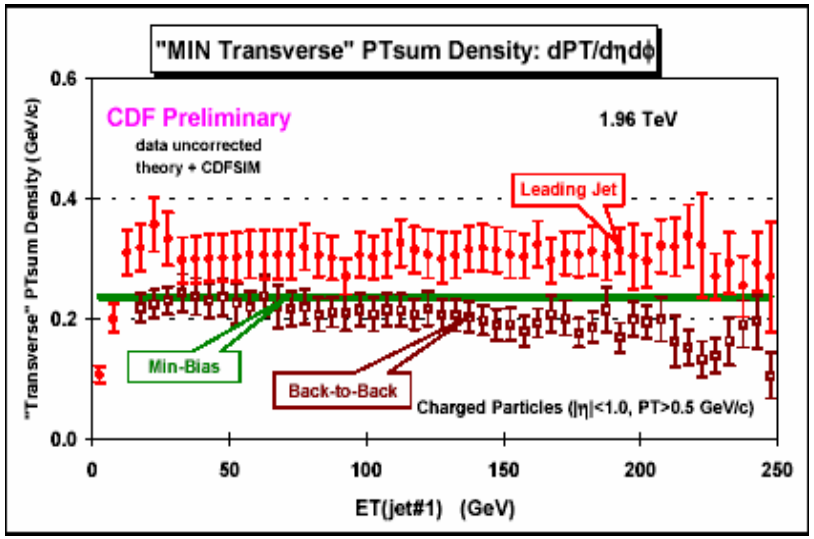
Transverse MIN region

"MIN" transverse region is more sensitive to the beam-beam remnant and to the multiple parton interaction component of "underlying event".

Expect "Leading jet" and"Back-to-back jet" events to be similar and both to be similar to Min-Bias collisions





Notice the decrease in the back-to-back data… !?!

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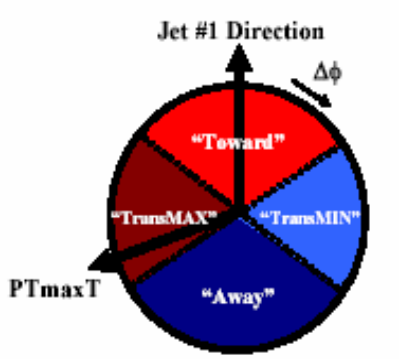
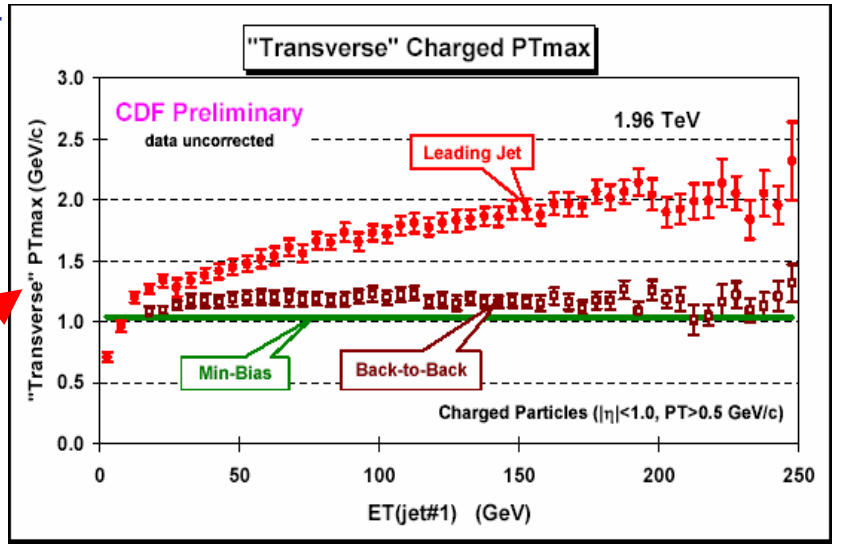
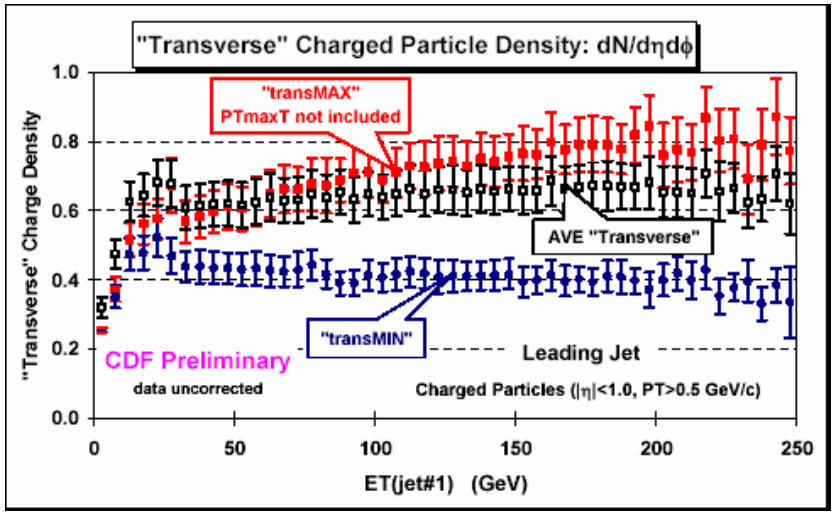
Transverse PTmax

- Define "PTmaxT" to be the highest P_T particle in the transverse region(s).
- Study densities "associated" with PTmaxT, *not* including PTmaxT
- Measure correlations in the transverse region



<PTmax> increase only for "leading jet" events.
In "back to back" is almost equal to MB.





Densities associated to PTmaxT **larger** than in average transverse region.

"Jet structure" in the underlying event at P_T ~ 1 GeV

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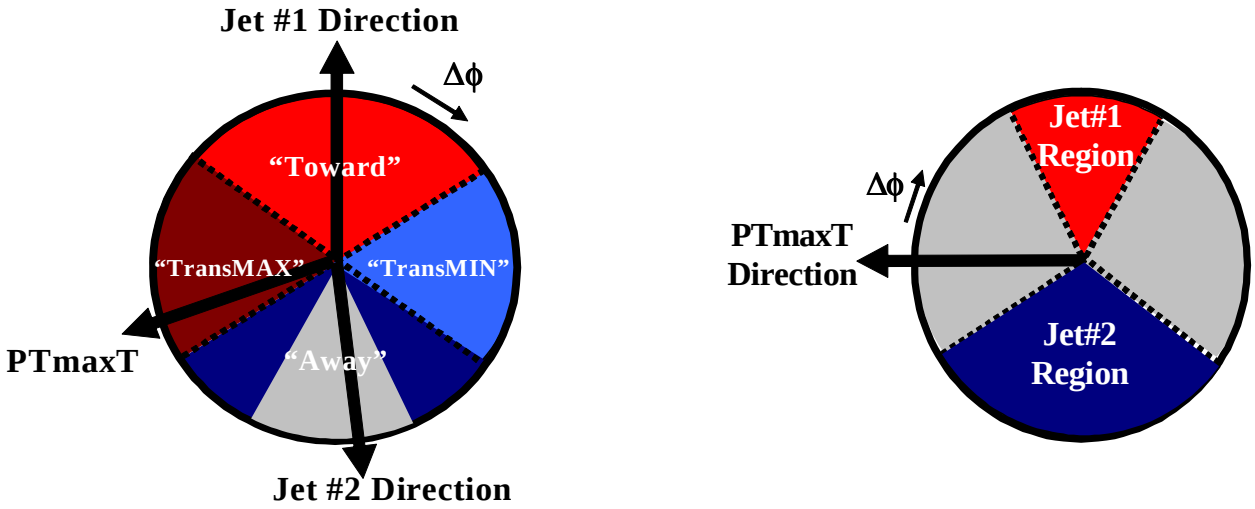
ΔΦ Correlations relative to PTmaxT



- PTmaxT defined to be the highest P_T particle in the transverse region :
  - "TransMAX" is the transverse region which contains PTmaxT
  - TransMIN" the opposite one
- Rotate PTmaxT in 180°:
  - Jet#1 will then be somewhere in 240° < ϕ<300° = TransMAX+90°
  - Jet#2 will then be somewhere in 30°< ϕ<150° = (jet#1 Region+180°)+/-30°
- Study Δϕ correlation of charged particles relative to PTmaxT

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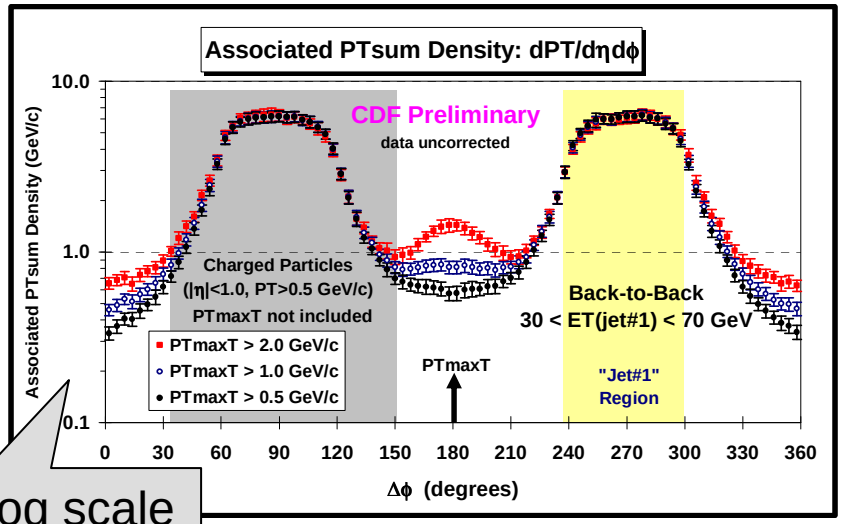
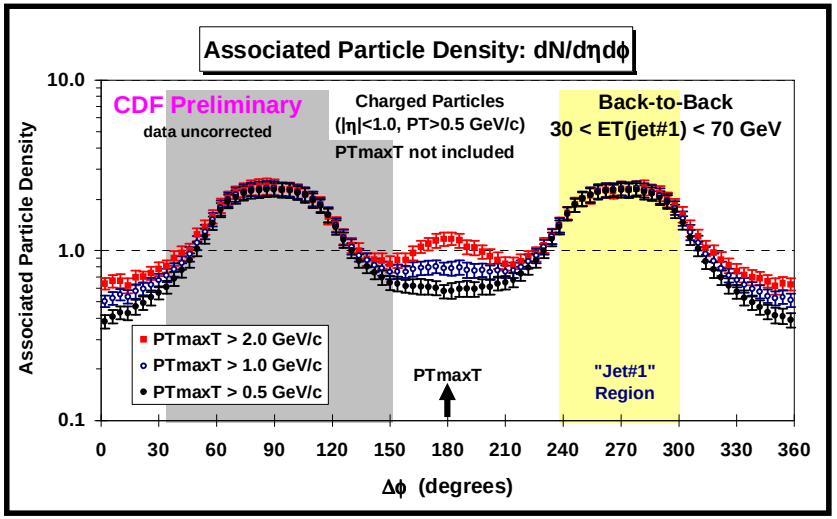
"Associate" density in b-t-b jet events

Back-to-back jet events: plot Δφ dependence of "associate" densities of charged tracks and scalar PTsum, relative to the direction of PTmaxT

Select PTmaxT : >0.5 , >1.0 , >2.0 GeV/c
"Associate" densities do not include PTmaxT itself





Log scale

Shows "jet structure" in the transverse region also in "back-to-back jet" events
(as can be expected, also in "leading jet" events, not shown here)

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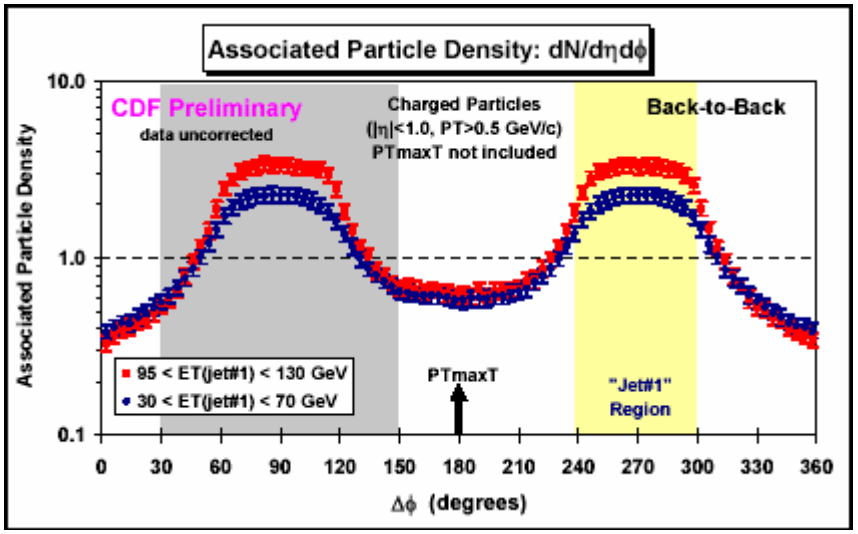
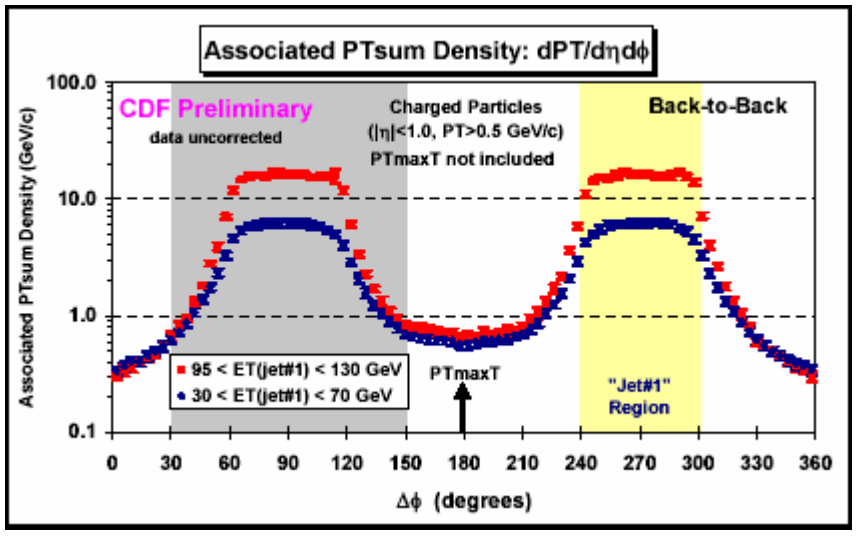
"Associate" density vs jet E_T

"Back-to-back" jet events: compare the" associate" density for events with different leading jet E_T

PTmaxT = 0.5 GeV/c here, same with 1.0 / 2.0 GeV/c

Behavior in transverse region changes with jet E_T in "leading jet" events





In "back-to-back" jet events the jet structure in the transverse region does not increase with the first jet E_T, since hard initial+final state radiation is strongly suppressed.

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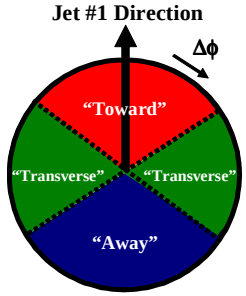
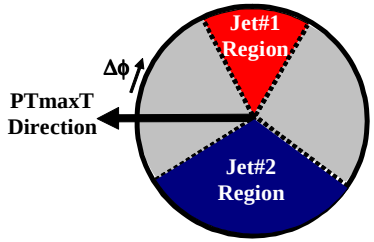
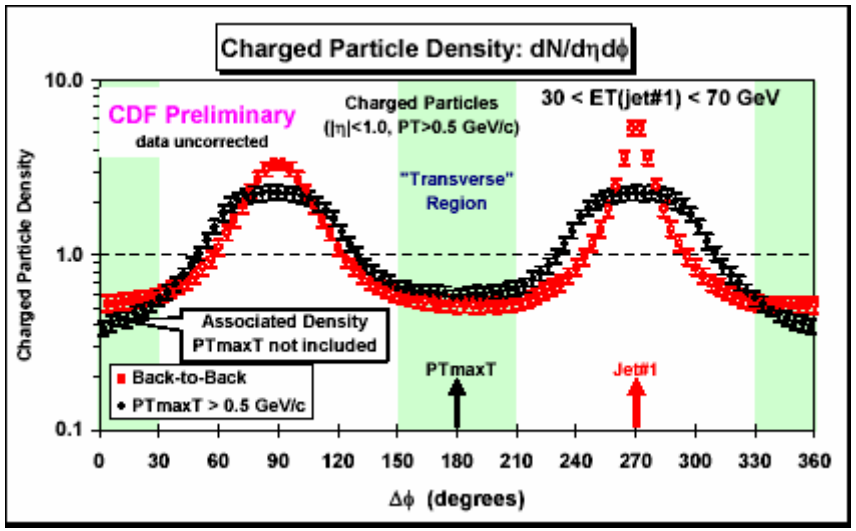
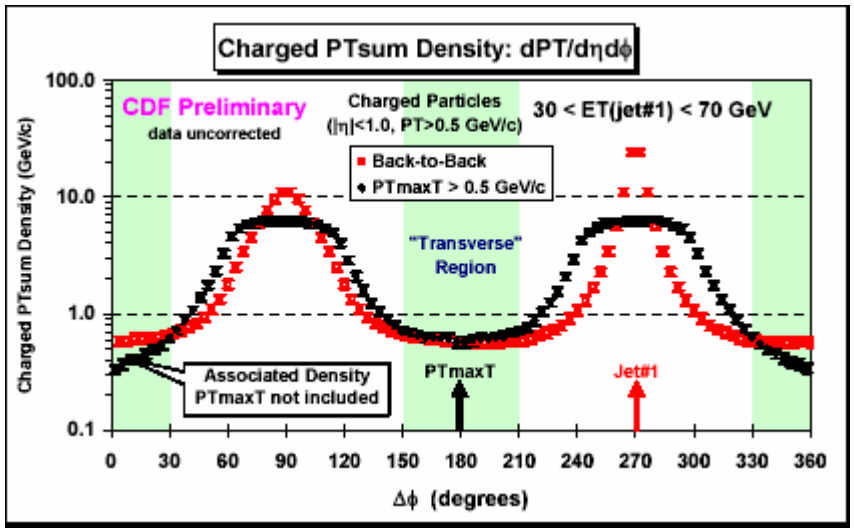
Compare the densities

"Transverse density" (previous) vs "associate density" (new)









The density of charged particle associated with PTmaxT is larger than the average density of particles in the transverse region also in "b-t-b jet" events

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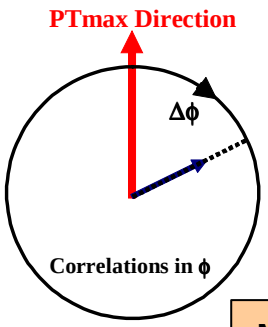
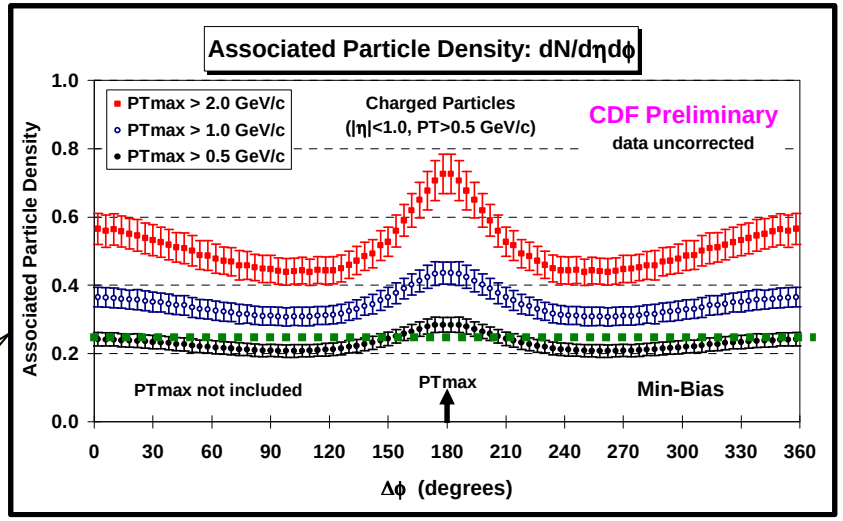
Min-Bias Events

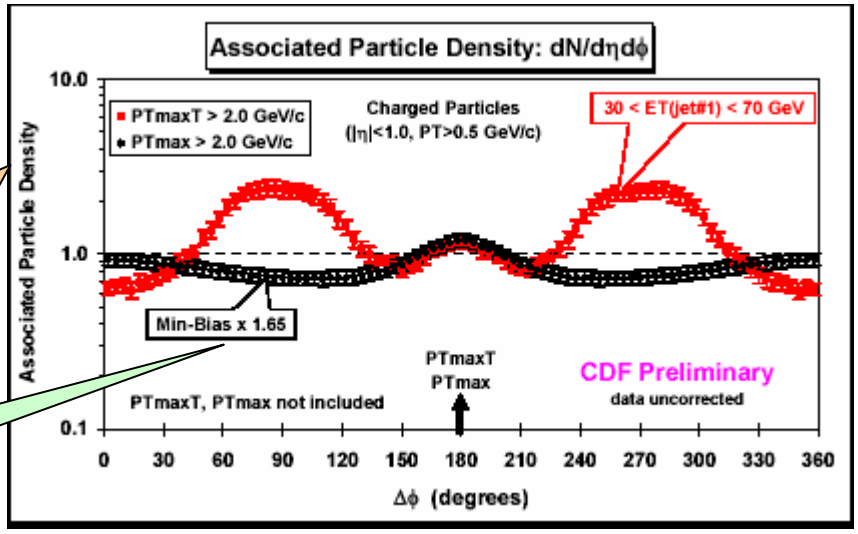
Min-Bias events: use the maximum P_T charged particle in the event, (PTmax) to define a direction and look at the "associated" density $dN_{chg}/d\eta d\phi$. Plot $\Delta\phi$ dependence of the "associate" particle density.



Jet structure of MinBias at P_T ~ 1GeV/c



Min-Bias vs "Back-to-back": Similar shape of particle density associate to PTmax in the transverse region.



Min Bias x 1.65 !!!

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Summary and Conclusions

A lot of work has been done in comparing the data with PYTHIA and HERWIG.
In general PYTHIA (tune A) is observed to work better.
For brevity reasons no comparison was shown here, but MC can provide an important handle to understand the details of the processes involved.

- ✓ We studied the density of charged particles and of the scalar P_T Sum in two "transverse" regions which are very sensitive to the "underlying event".
- ✓ By selecting a subsample of "back-to-back" jet events we looked closer into the "beam-beam remnant" and multiparton interaction component of the "underlying event": this component is very similar to MB and flat with respect to the jet E_T.
- ✓ To examine the jet structure of the "underlying event" we studied the $\Delta\phi$ dependence of the particle density associate to the maximum P_T particle in the transverse region: data show strong correlation in the transverse region which indicate a "jet structure" in the "underlying event" for both "leading jet" and "back-to-back jet" events.
- ✓ Min-Bias data also show a "jet structure" at low P_T (~1 GeV/c) which is similar to that of hard "back-to-back" jet events.